DOT/FAA/AR-02/34

Office of Aviation Research
Washington, D.C. 20591

Survey of Aviation Technical Manuals Phase 2 Report: User Evaluation of Maintenance Documents

May 2002

Interim Report

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-02/34		

4. Title and Subtitle	5. Report Date
SURVEY OF AVIATION TECHNICAL MANUALS PHASE 2 REPORT: USER EVALUATION OF MAINTENANCE DOCUMENTS	May 2002
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Alex Chaparro, Loren S. Groff, Barbara S. Chaparro, and Deborah Scarlett	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
National Institute for Aviation Research Wichita State University 1845 Fairmount Wichita, KS 67260	11. Contract or Grant No. 00-C-WSU-00-12
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591	Interim Report 01/11/01-11/06/01
	14. Sponsoring Agency Code AFS-300

15. Supplementary Notes

The FAA William J. Hughes Technical Center Technical Monitor was Cristina Tan.

16. Abstract

This report contains the results from Phase 2 of a 3-phase research effort. Phase 1 (Human Factors Survey of Aviation Technical Manuals Phase 1 Report: Manual Development Procedures) of this research effort surveyed the procedures used by five manufacturers to develop maintenance documentation. Several potential human factors issues were identified in the development processes employed by these manufacturers. They included the reactive rather than proactive use of user evaluations, the limited use of user input and procedure validation, no systematic attempts to track error, and the lack of standards for measuring document quality. In Phase 2, a written survey was used to solicit information about user perception of errors in current manuals, manual usage rates, and general manual quality. On-site interviews of technicians were also conducted to gather feedback about the types of problems encountered with manuals, the associated impact, and suggestions for improving manuals. Feedback was obtained from technicians responsible for maintenance on a wide variety of Federal Aviation Regulations, Part 25 aircraft. Survey results revealed that, although user evaluations of the accuracy and quality of technical manuals are generally good, they rate manuals as having poor usability. Comparing the results of Phase 1 to the Phase 2 results supports the need for a higher level of user involvement during the document development process.

17. Key Words	18. Distribution Statement
Error, Human Factors, Maintenance manuals	This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	34	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Until recently, little attention has been paid to the way written procedures which are used to develop and revise aircraft maintenance technical data affect the users of that data. Studies of maintenance problems have tended to focus on the actions of the mechanic, job culture, and work procedures. More recently, attempts have been made to document the source of maintenance errors and improve maintenance procedures. One of the identified contributing causes of errors is the documentation used to guide maintenance tasks. As a result, efforts have been made to establish guidelines for the design of maintenance job aids. A question that remains is how the procedures used by manufacturers to develop maintenance data may contribute to user error.

This report contains the results from Phase 2 of a 3-phase research effort. This phase (1) examines the procedures used by industry to develop aircraft maintenance manuals, (2) documents the problems encountered by the users of these documents, and (3) identifies ways in which human factors principles can be used to improve the development of these documents. This phase includes a survey and interviews of technicians responsible for maintenance of a wide variety of Federal Aviation Regulations Part 25 aircraft. Technicians were queried about technical manual usage rates, manual errors, general manual quality, potential safety impact of manual problems, and suggestions for manual improvement. In summary, the results show that the accuracy and quality of technical manuals are rated as being good but have poor usability. In light of the results of Phase 1, these results support the need for a greater degree of user involvement during the document development process.

1. INTRODUCTION.

The Federal Aviation Administration (FAA) has committed themselves to the goal of reducing fatal aircraft accidents by 80% (based on 1996 baseline rate) by the year 2007 [1]. An important part of accident reduction is to reduce the number of errors generated during the maintenance of aircraft. In an analysis of aircraft maintenance error causation, Johnson and Watson [2] identified information as being the highest ranked contributing cause, which was implicated in approximately 38% of all maintenance errors. An analysis of National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System data, regarding maintenance incidents, found document procedures to be related to 60% of incident reports from 1986 to 1992 and 45% of incidents from 1996 to 1997 [3]. Further analysis of the errors attributed to information revealed that incorrect data was a factor in only a small number of these cases, and many of those cases were user-initiated problems. The most common problem appeared in cases where the information was not being referred to, misunderstood, or disregarded in favor of an alternate method of performing a maintenance procedure. Given the number of cases in which technicians fail to properly use maintenance information; one might conclude that the problem should be addressed through training or disciplinary action toward the maintenance workforce. However, rather than indicating a systemic discipline problem with maintenance technicians, or laissez-faire attitude toward technical documents, it could reflect a problem with the usability of technical documents.

Maintenance manuals can contribute to maintenance error if they contain misleading information, insufficient information, or unclear procedures. Not only must the information be technically sound, it must also be presented in an effective manner. A term common to the computer industry, and most applicable in this case, is "usability." Usability can be defined in a broad sense as "the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component" [4]. When applied to aircraft manuals, usability includes the user's experience with manuals; how easy they are to use, how well they match the technician's representation of a task, how easy they are to read and interpret, and the usefulness of the information they contain. The amount of experience the user has had with manuals influences how they use them and the degree to which they refer to them.

1.1 BACKGROUND.

One of the problems identified in Phase 1 of this effort [5] was the lack of a systematic method for the evaluation of manual quality by manufacturers. Evaluations may consist of peer review, grammar and spell checking, and critical reviews of layouts to assure adherence to standards. All of these procedures are necessary components of the error-checking process. A fundamental step in the development of a quality technical document is to determine that the intended message is presented clearly and without error. The results of the user surveys indicate that, for the most part, manufacturers have done a good job in this area. Not only does the summary of responses reflect a favorable evaluation of the quality and consistency of documents by technicians, but the evaluations are remarkably similar when analyzed by individual manufacturers. While the actual error rate is difficult to determine, it is not of sufficient size to create a negative perception on the part of technicians.

Compliance with standards for design and development insure that the technical documents have a consistent "look and feel." Design standards are defined by company policies and procedures, or may be part of industrywide efforts such as the Air Transport Association (ATA) formatting specification. Systematic procedures for verifying the accuracy of technical information reduce the number of errors (typographical and factual). Adherence to standards can be accomplished through oversight within the organization, or it may be more formal as in the ISO 9000/9001 certification. However, adherence to company procedures and design standards alone does not guarantee that the product will be easy to use.

1.2 PROJECT OBJECTIVES.

Phase 1 of this research effort surveyed five manufacturers concerning the procedures they use to develop maintenance documentation. Several human factors issues were identified in the development process employed by these manufacturers. They included the reactive rather than proactive use of user evaluations, the limited use of user input and procedure validation, no systematic attempts to track errors, and the lack of standards for measuring document quality. Given the issues identified in Phase 1, the objective of Phase 2 was to gather information about errors in technical documents, manual usage rates, and user perceptions of manual quality. Respondents were also asked to identify the types of problems encountered with technical documents, the impact of those problems, and suggestions for improving manuals. Information was gathered on the differences between manuals developed by different companies. Considering the variability of methods used by manufacturers to develop technical documents, it may be possible to identify techniques and procedures that result in more effective documentation. The goal of Phase 3 will be to outline recommendations and procedures for improving document usability.

2. METHODS.

2.1 SURVEY.

2.1.1 Recruiting Participants.

Phase 1 of this effort focused on the procedures used by manufacturers to develop and revise the technical documentation to be used in the maintenance of their aircraft. In order to determine the potential effects of these procedures on document quality and usability, a survey was developed to measure technician perceptions of maintenance documents. In addition to general perceptions of documentation quality and usability, respondents were asked to compare the documentation produced by different manufacturers so that differences in user evaluation might be traced directly to the procedures used by a particular manufacturer.

In order to gather the most representative sample possible, participation was solicited from operators and facilities responsible for the maintenance of a variety of Federal Aviation Regulations (FAR) Part 25 aircraft. Agreement to participate was first obtained from the corporate offices of the aircraft operator. Eleven facilities providing maintenance services for regional and privately owned FAR Part 25 aircraft were contacted for the study and agreed to participate. Seven facilities responsible for providing maintenance on large FAR Part 25 aircraft were also contacted, and two agreed to participate. Two other companies deferred participation to a later date, and that data will be included in a subsequent report. Following corporate approval, the associated local labor union representatives were contacted, provided with a description of the intent and the purpose of the project, and asked to participate in the project. Participants were informed that all information was confidential and that they would not be identified in any of the reports. The majority of completed surveys for large FAR Part 25 aircraft were obtained from the maintenance facilities operated by one major airline, and a company providing maintenance, repair, and overhaul services to airlines.

2.1.2 Survey Description.

The survey (see appendix A) solicited information from the respondents about a number of areas, including the aircraft they currently work on and their specialty area. Participants were then asked to identify the two aircraft with which they were most familiar, and to compare the frequency of errors, perceptions of quality, satisfaction, and usability, of those manuals. Next, the respondents were asked to report how frequently they had engaged in safety related maintenance behaviors, and to identify the consequences of errors or confusing information they have encountered in the manuals. Finally, information was solicited about document format preferences and suggestions for improving the manuals. Biographical information, including education level and employment experience, was collected for the purpose of identifying any trends in user responses that may have been due to individual differences. Responses to assessments and ratings of the manual were reported using a 5-point Likert scale. Other data was recorded as discrete or narrative responses when appropriate.

2.1.3 Survey Distribution.

A designated person at each company was responsible for distributing and collecting completed surveys from employees. The survey was available as a four-page paper document and as a web-based form (www.niar.twsu.edu/faaq) to increase the scope of distribution. Both paper and web-based surveys were accompanied by a cover letter describing the purpose of the project and emphasized the confidential nature of the responses.

2.2 INTERVIEWS.

In addition to the questionnaire, site visits were made to one regional operator and two major airline facilities. The employees who use the manuals at these facilities were interviewed to verify the reliability and validity of survey responses, as well as providing additional detail and clarification of the survey data. Interviews were conducted with personnel involved in all areas of aircraft maintenance, including technicians, supervisors, engineers, parts supply, and task card writers. Interview participants were asked to identify areas of strength and weakness in the technical documentation provided by manufacturers, to compare and contrast different manufacturers, to assess the potential impact of document quality, and to make suggestions for any improvements that could be made to manufacturers' documents. Whenever possible, interviews were conducted in groups of twos or threes to facilitate discussion and to limit peer influence that might be present in a larger group. As with the surveys, agreement to participate was obtained from the corporate offices of the aircraft operator and the local labor union representatives. All interview participants were informed that the information they provided would be confidential. They were also assured that names of individuals and their respective companies would not be identified in any of the reports.

3. RESULTS.

3.1 SURVEY RESPONSE.

Completed surveys included feedback from technicians at both line- and heavy-based maintenance facilities. Figure 1 shows the manufacturers of the aircraft that technicians maintain, and their relative frequency. The most frequently cited manufacturers were Boeing, McDonnell Douglas, Cessna, and AirBus. The majority of responses came from major airline facilities. To date, 377 individual survey responses and 745 unique aircraft evaluations have been received. Of these responses, the 296 individual survey responses and 579 unique aircraft evaluations came from major aircraft operators. The remaining responses came from maintenance facilities responsible for regional and/or privately owned FAR Part 25 aircraft. Figure 2 shows the relative percentage of responses for large and smaller FAR Part 25 aircraft, respectively. The relative proportion of different aircraft types reported in the survey appears to be representative of the number in active service.

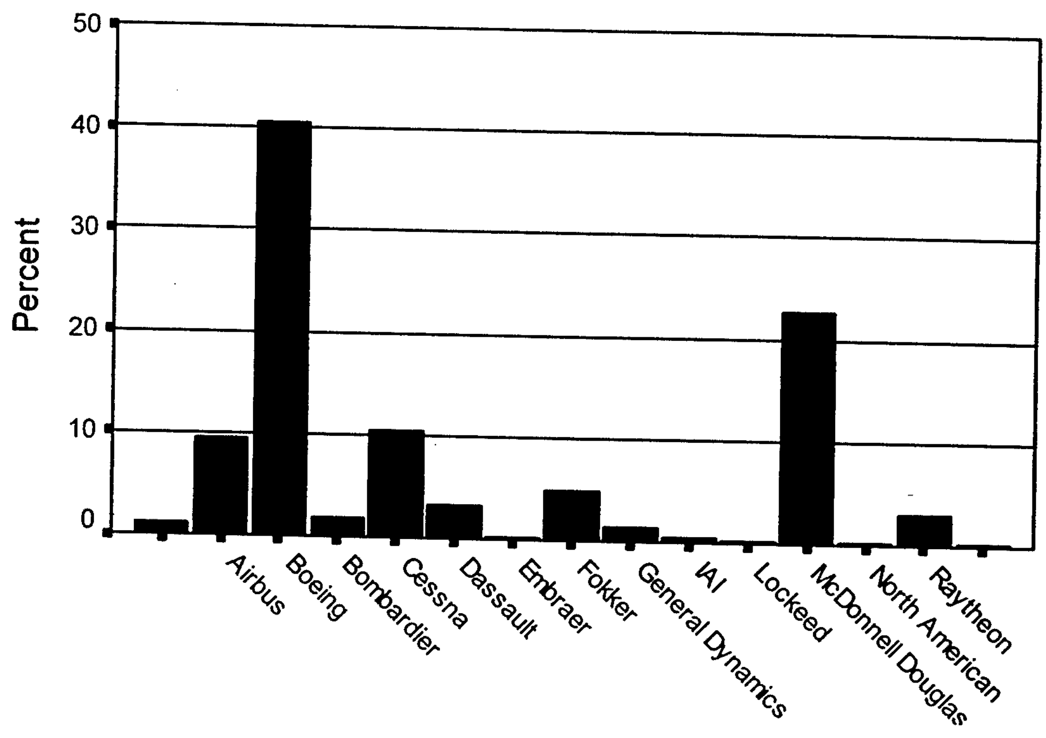


FIGURE 1. AIRCRAFT MANUFACTURERS REPRESENTED

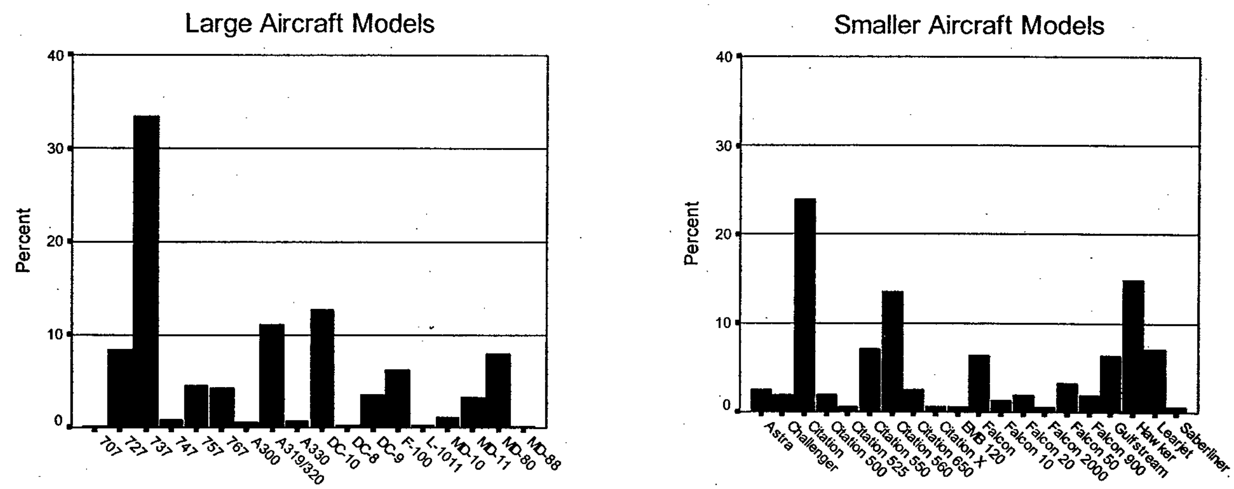


FIGURE 2. AIRCRAFT MODELS REPRESENTED (Large and smaller)

3.2 DEMOGRAPHICS.

A summary of the demographic characteristics of the survey respondents is shown in table 1. The results reveal that the sample is almost exclusively male, is highly experienced, and consists of almost equal numbers of line and base maintenance personnel, which the vast majority are FAA certified.

TABLE 1. RESPONDENT DEMOGRAPHICS

Mean Age	The average age of respondents was 45 years, with the distribution ranging from 22 to 69 years. Age was normally distributed, with the bulk of responses coming from technicians 39 to 46 years of age.
Sex	With the exception of a single technician, all respondents were male.
Education	The majority of respondents (54%) indicated having some college education. 12.5% report having a Bachelor's degree or higher.
Certification	92% of all respondents and 94% of respondents working for major airlines were FAA certificated maintenance technicians.
Type of Maintenance	51% of responses were from technicians responsible for Line Maintenance, while the remaining 49% were responsible for Base Maintenance, or a combination of Line and Base Maintenance.
Experience	The average work experience reported was 14 years as a technician, and 13 years with their current company.
Military Training	58% of respondents report some military experience.

3.3 SURVEY QUESTIONS.

The first group of survey questions addressed the usage rates and the perception of quality of manuals. Respondents were asked to identify the two aircraft types they are most familiar with and compare them on each set of ratings.

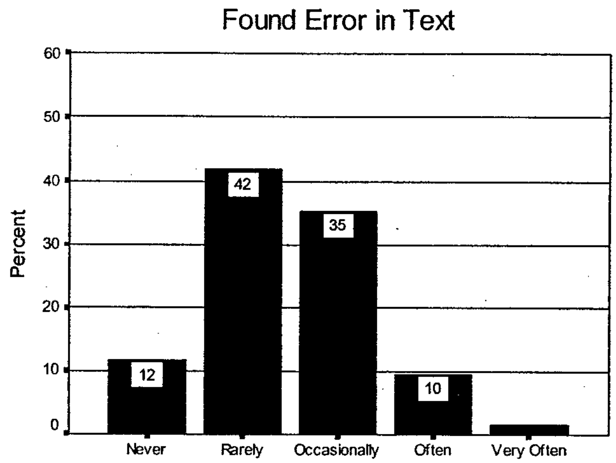
3.3.1 Manual Usage.

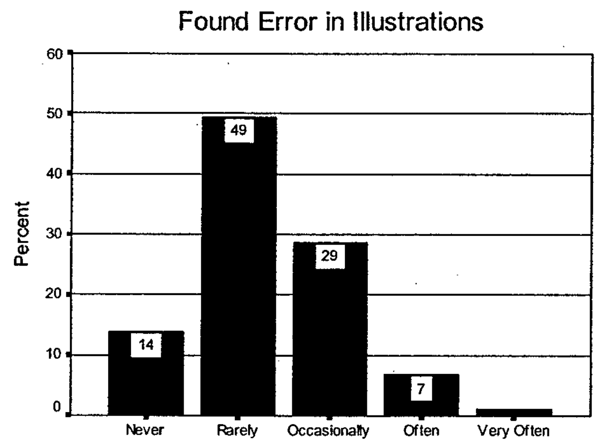
Responses indicated that the Aircraft Maintenance Manual (AMM), Illustrated Parts Catalog, and task cards were the most frequently used technical documents. It should be acknowledged that because the survey sample included a large cross-section of maintenance operations, the technical documentation used by any particular technician will differ depending on whether they are doing line or base maintenance, and the degree to which they specialize in specific maintenance tasks. For example, scheduled base maintenance will rely more heavily on the use of task cards, while the unpredictable nature of line maintenance requires the maintenance manual and parts catalog to be used more frequently. It should be emphasized that the focus of this survey and evaluation was the AMM and not job task cards. Interested readers should consult the work of Drury and colleagues [6] which focuses on the unique design and usability issues associated with task cards.

3.3.2 Error in Manuals.

After establishing manual usage rates, technicians were asked to report how often they found errors in text procedures, illustrations, and diagrams.. One of the larger goals of this project was to determine the degree of error present in technical manuals. Respondents were asked to rate, on a 5-point Likert scale, from “never” to “very often” how often they have encountered errors in manual text, diagrams, and procedures. While subjective, the results (see figure 3) show that most respondents reported rarely or never finding errors in manual text (54%), illustrations (63%), and diagrams (66%).

Similar results are observed when responses are separated by aircraft size (e.g., aircraft operated by major airlines versus smaller FAR Part 25 aircraft). A statistical comparison of large and smaller aircraft reveals significant differences only in user ratings of the frequency of text errors, with error being reported more frequently in smaller FAR Part 25 aircraft. This comparison can be seen in figure 4. A complete copy of the statistical analysis and results are available in appendix B.





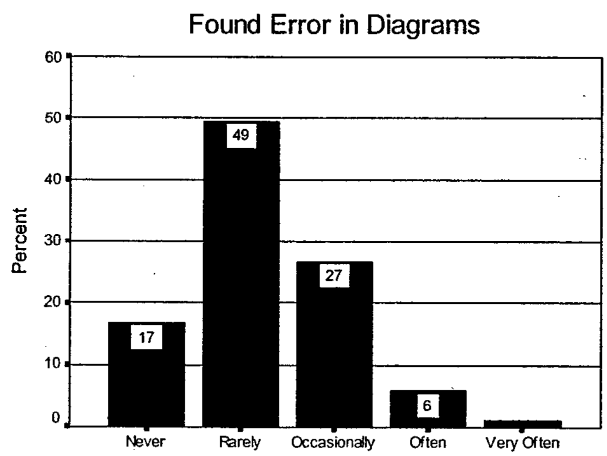


FIGURE 3. ERROR REPORTED FOR ALL AIRCRAFT

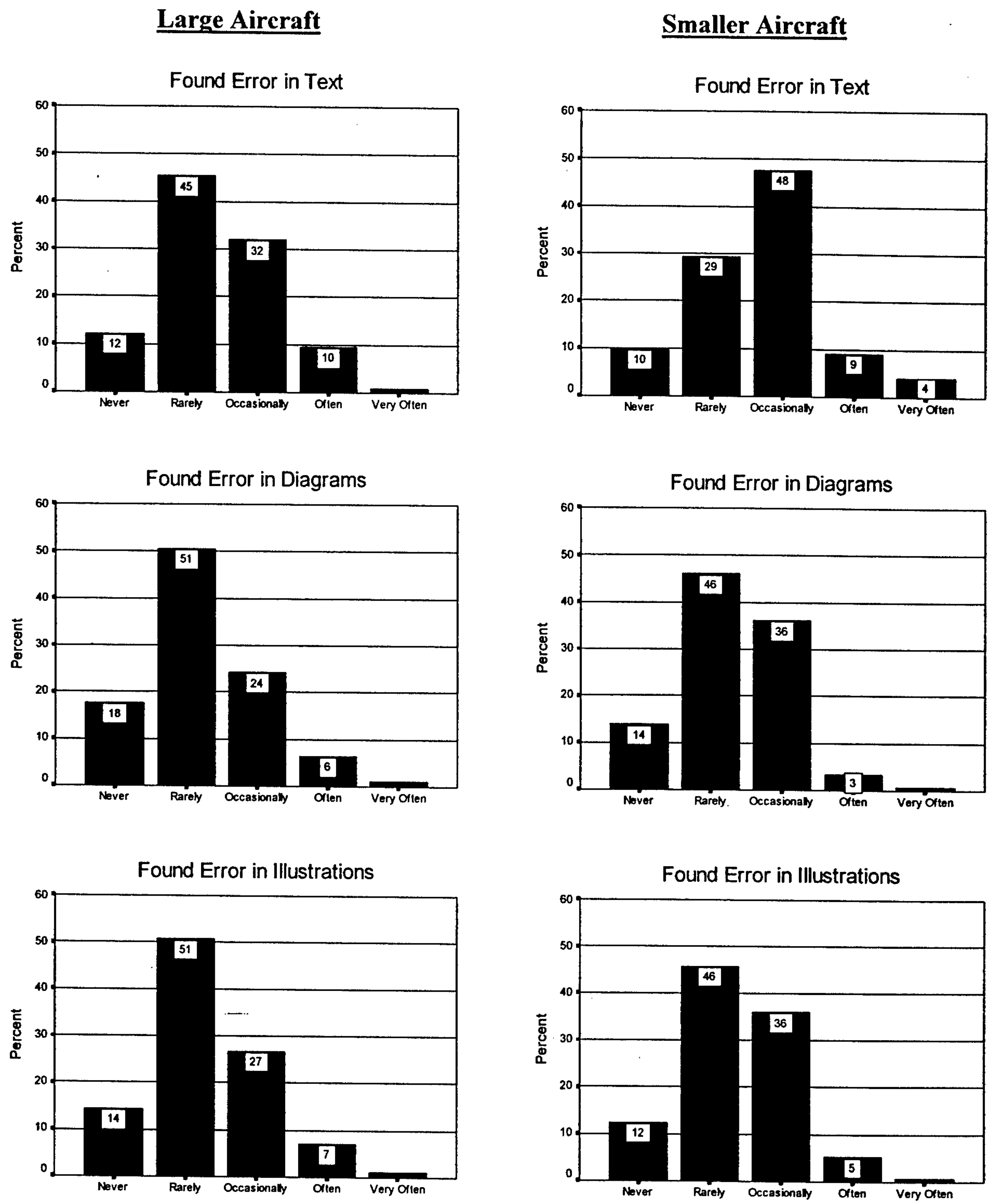


FIGURE 4. ERROR REPORTED FOR LARGE VERSUS SMALLER AIRCRAFT

3.3.3 General Manual Quality.

The next series of questions on the survey queried the user's perception of general manual quality. Respondents were asked to rate from "very poor" to "very good" on the usefulness of manuals, the quality of manuals and diagrams, and the clarity of text descriptions. Figure 5 shows that the technicians rate maintenance manuals as being very useful to the job they perform (74% "good" or "very good") and perceive the manuals as being of generally good quality (56%) with good quality diagrams (54%) and text clarity (47%).

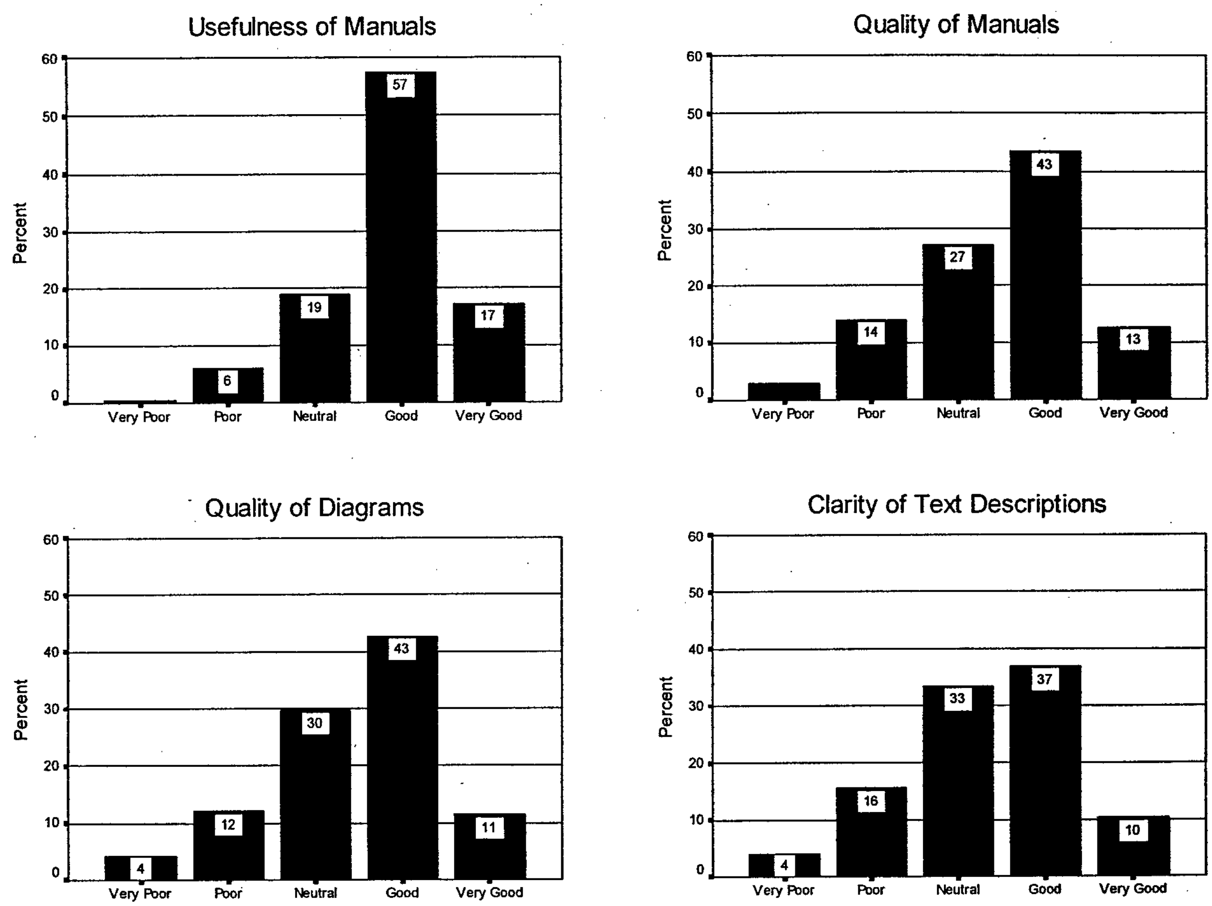


FIGURE 5. PERCEPTION OF GENERAL MANUAL QUALITY

In addition to distinctions between large and smaller aircraft manufacturers, it is important to investigate potential differences between manufacturers of similar aircraft. If one manufacturer is consistently rated higher than their competitors, this may be indicative of superior manual development techniques. Figure 6 represents a sample of data from the four large aircraft manufacturers referred to most often in this survey. Closer scrutiny of these figures reveals that the quality of the manuals is roughly comparable for three of these manufacturers, while the fourth is noticeably worse. From these results, it appears that even though each manufacturer employs different manual development procedures, most result in manuals that are perceived to be of similar quality. The poorer ratings of manufacturer D may be accounted for by the fact that this particular manual was translated into English and is reported to be a paper-based version of what was originally intended to be an electronic manual (i.e., CD-ROM).

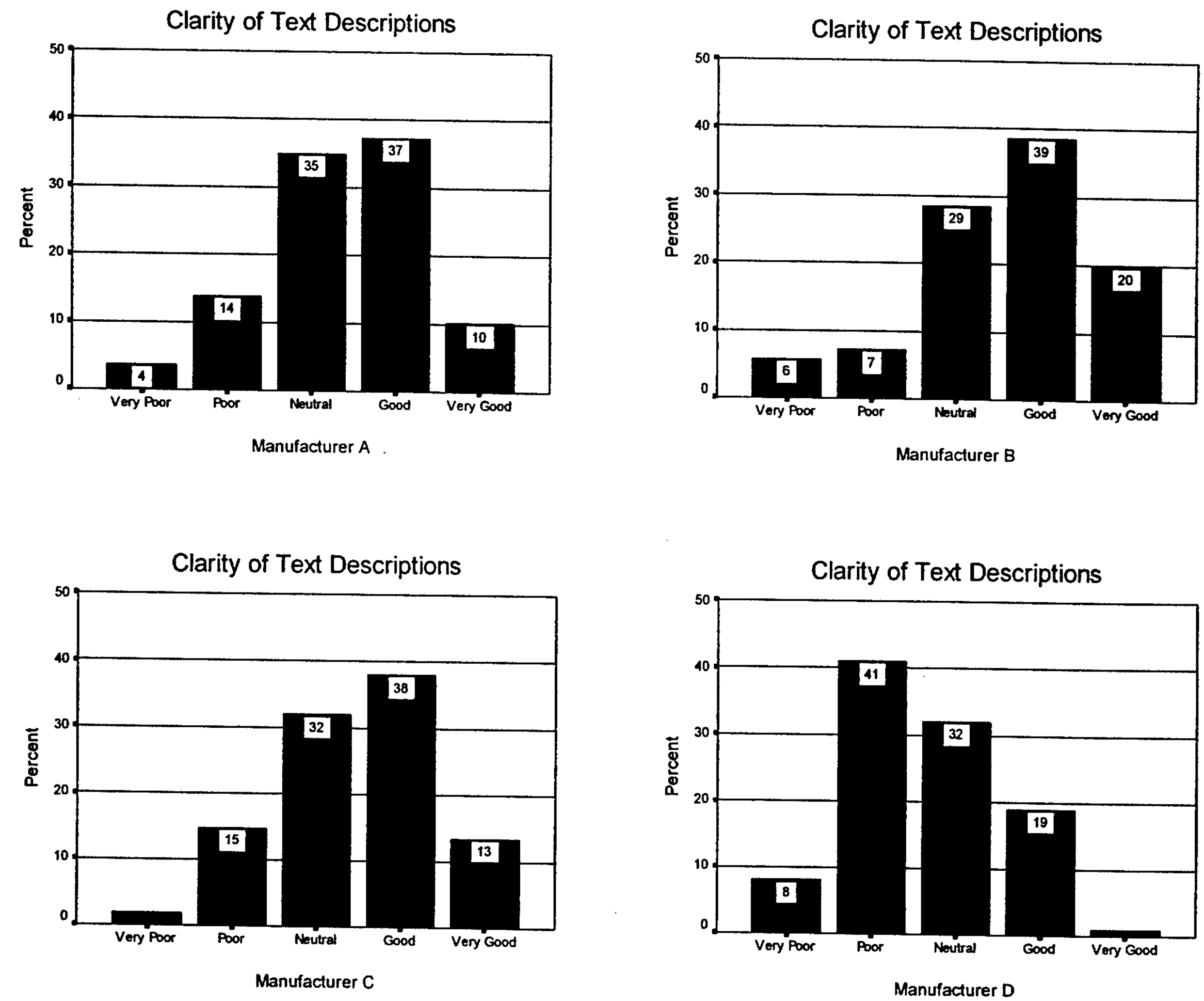
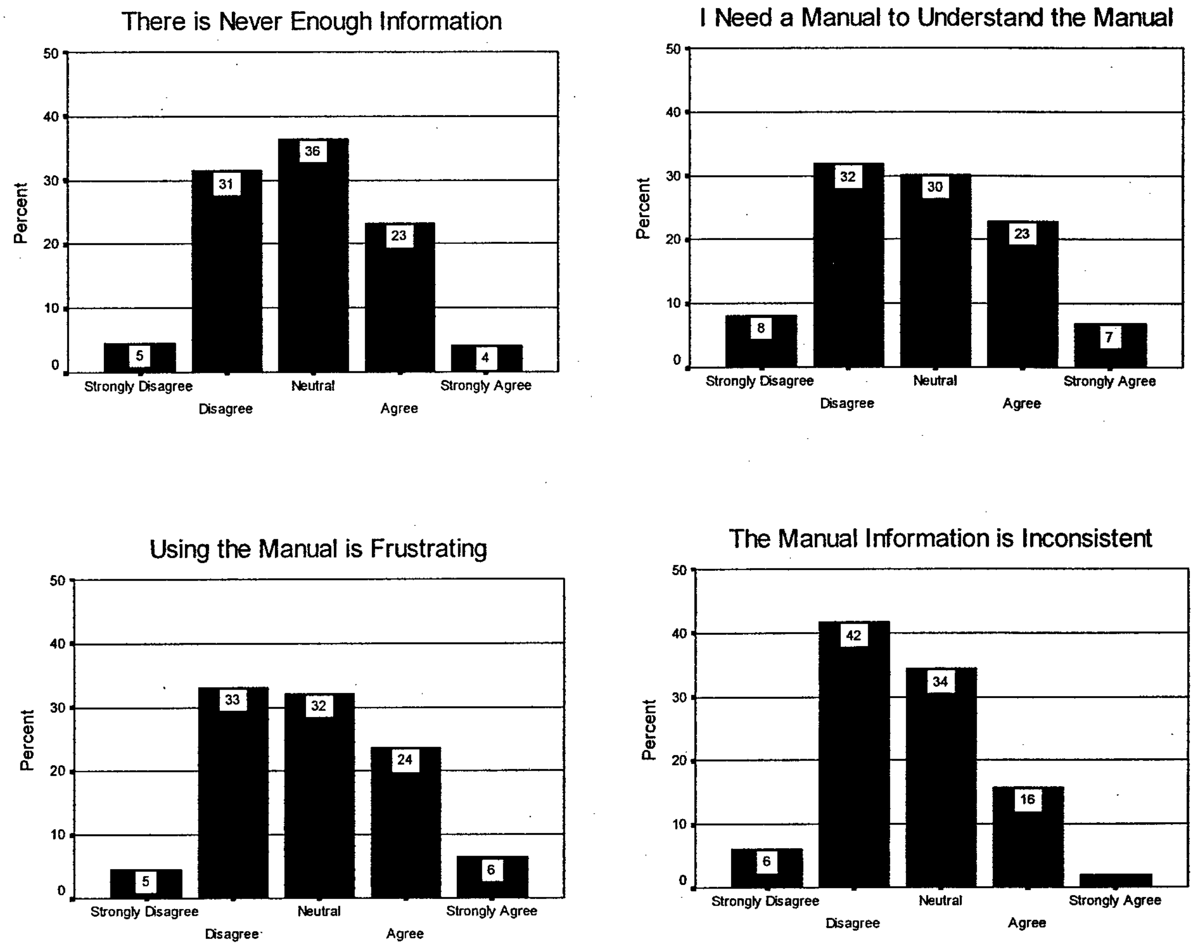


FIGURE 6. EXAMPLE OF DIFFERENCES IN PERCEPTIONS OF TEXT CLARITY BY MANUFACTURER

3.3.4 Usability.

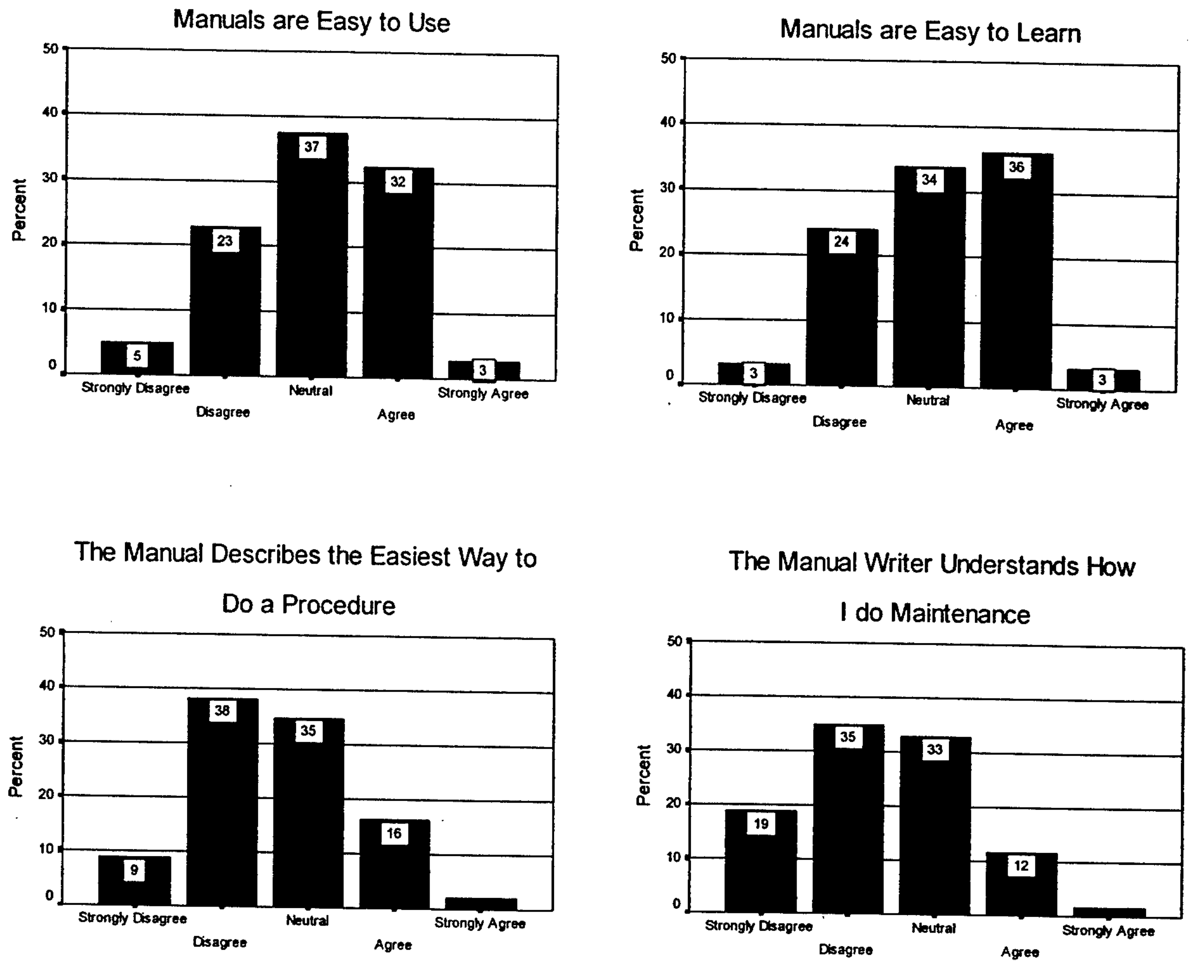
The next set of survey questions were designed to investigate user perceptions of manual usability. Usability issues surveyed included the ease of manual use, the consistency and clarity of the manual, and the depth of information. The respondent answers shown in figures 7(a) and 7(b) are normally distributed with the mean centered near neutral or shifted slightly toward the positive end of the scale. In general, technicians consider maintenance manuals easy to learn, easy to use, clear, and consistent.



(a)

FIGURE 7. MEASURES OF MANUAL USABILITY

The final two usability questions assess how well the described procedures match the way technicians actually do their job. When asked to respond to the statement, "the manual describes the best way to do a procedure," 47% of technicians say they disagree or strongly disagree. The statement, "the manual writer understands the way I do maintenance," resulted in 54% of technicians responding that they disagree or strongly disagree.

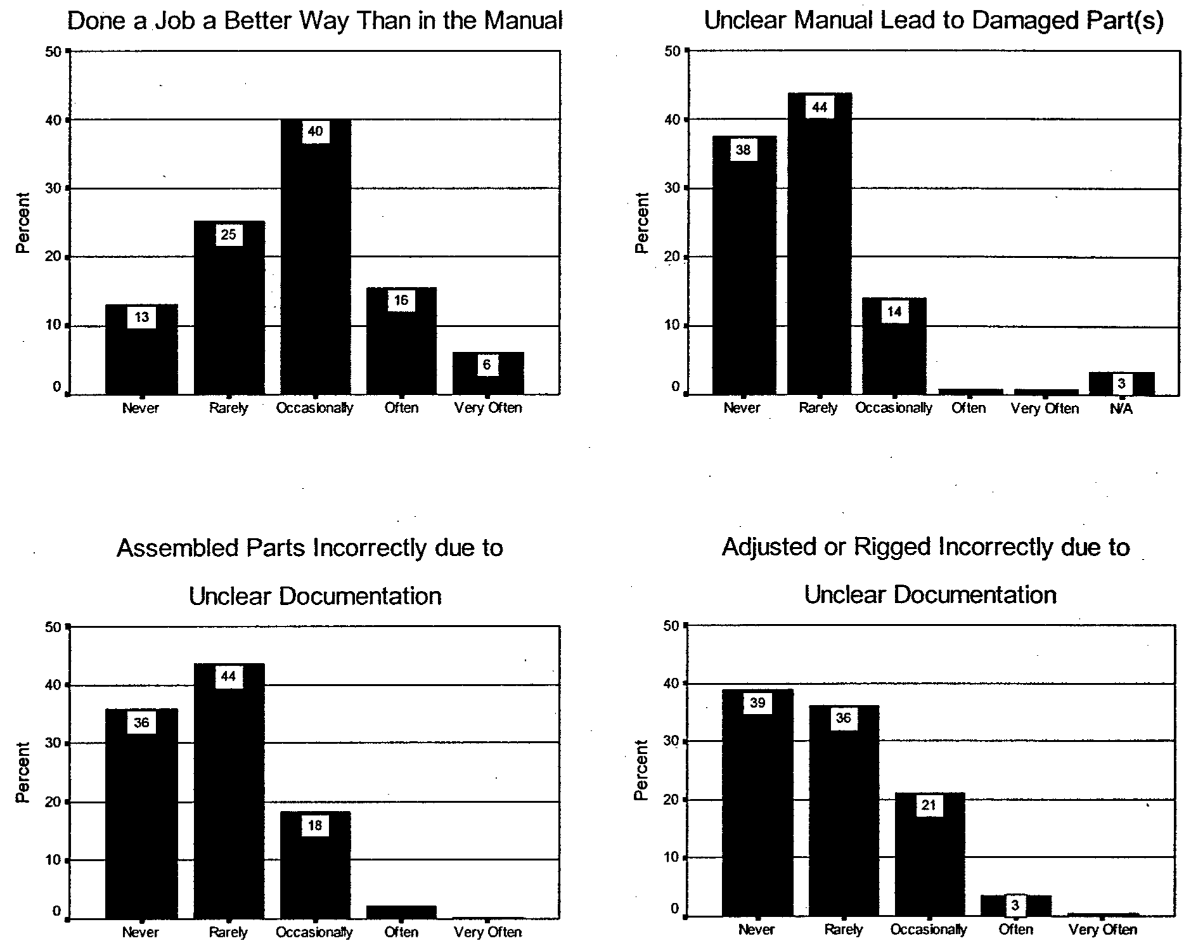


(b)

FIGURE 7. MEASURES OF MANUAL USABILITY (Continued)

3.3.5 Impact of Manual Usability.

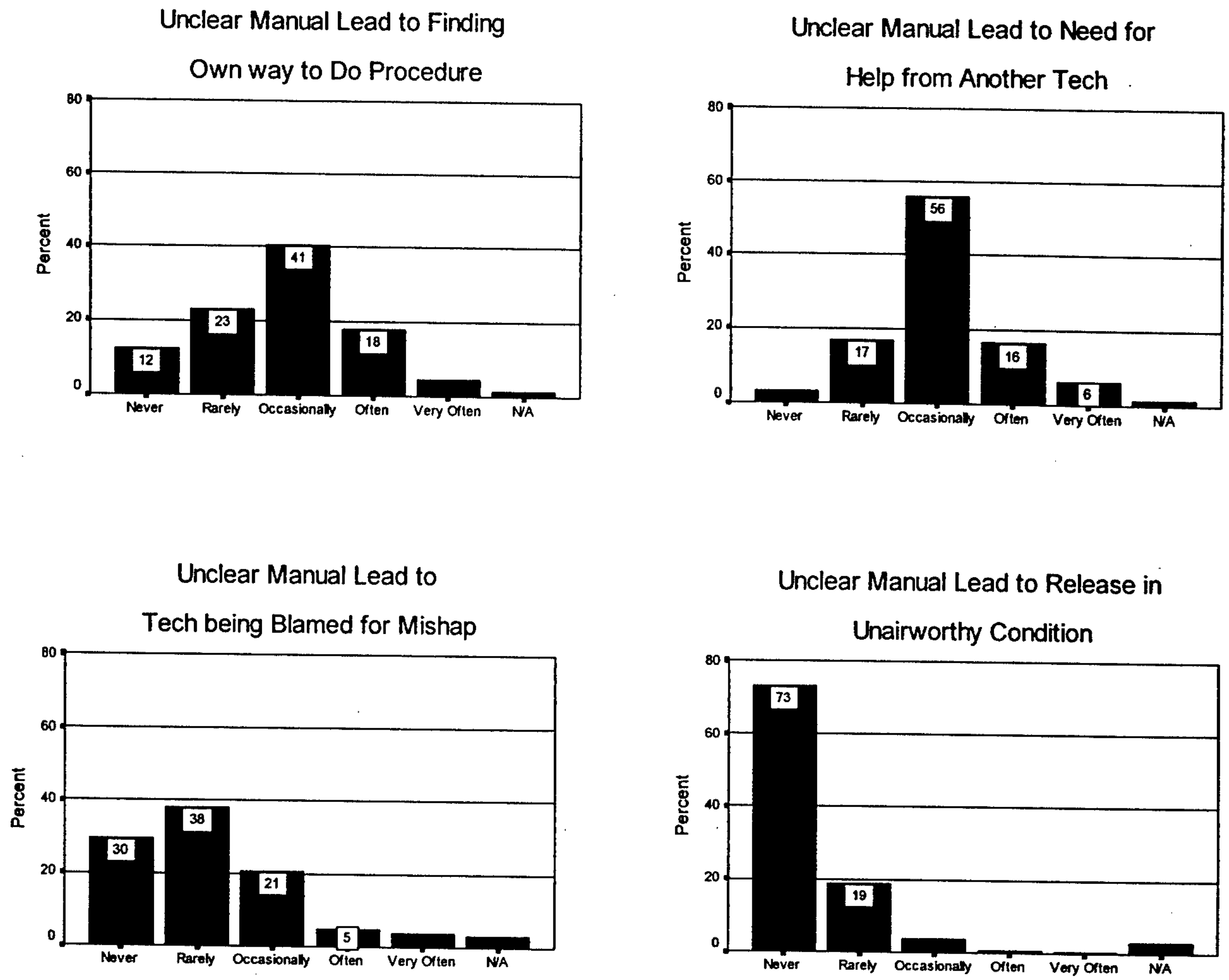
Figures 8(a) and 8(b) show the results of questions designed to assess the potential impact of document usability. As can be seen in figure 8(a), 62% of the respondents reported completing a procedure in a way they considered "better" than what was described in the manual. As a result of unclear or misleading procedures, 18% of the respondents reported parts being damaged, 20% reported assembling a component incorrectly, and 25% reported having adjusted or rigged a system incorrectly.



(a)

FIGURE 8. REPORTED IMPACT OF USABILITY PROBLEMS

Seventy-eight percent of respondents reported that they consulted another technician when confronted with a confusing procedure and 64% reported finding their own way of performing a procedure. Only 5% reported that these difficulties resulted in an aircraft being released in unairworthy condition, but 30% reported seeing a technician being blamed for a mishap stemming from difficulties interpreting the manual.



(b)

FIGURE 8. REPORTED IMPACT OF USABILITY PROBLEMS (Continued)

3.3.6 Reporting Problems.

In order to determine the effectiveness of the procedures intended to provide feedback to manufacturers about the problems users encounter within the manual, respondents were questioned about how likely a technician is to report an identified error. The results presented in figure 9 indicate that 45% of respondents say they will often or very often report errors when they find them. Fifty-three percent reported that they report the errors they find only occasionally, rarely, or never.

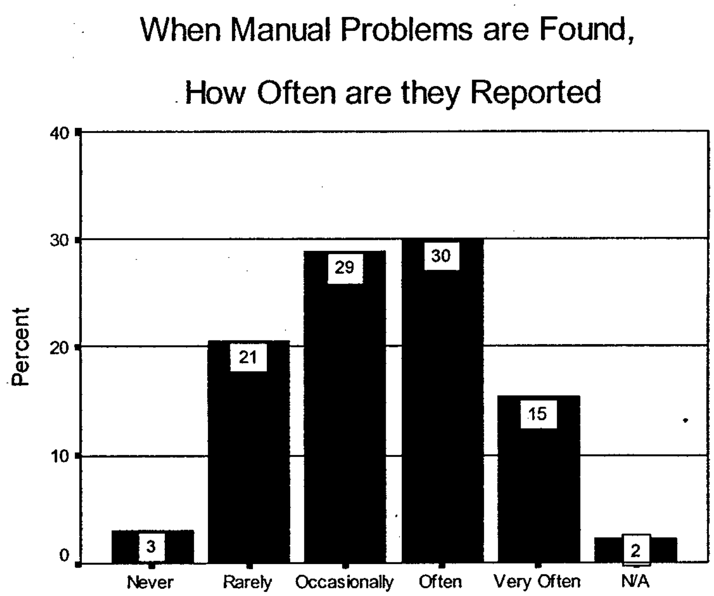


FIGURE 9. REPORTING IDENTIFIED PROBLEMS

3.4 TECHNICIAN COMMENTS.

The survey contained a section wherein the participants were asked open-ended questions about their preferred manual delivery mode (CD, paper manuals, and microfiche) and recommendations for improving the manuals. These results are discussed below.

3.4.1 Format Preference.

Although this research effort does not address the unique differences between manual formats, it is important to acknowledge the usability issues associated with different delivery formats (e.g., CD, microfiche, and paper manuals). For example, the problems of determining effectivity of parts and systems modifications can be more easily addressed in electronic format manuals by linking the aircraft registration number to a database of parts and systems modifications. However, the use of electronic manuals raises usability concerns of interface and display design, information presentation, computer accessibility and portability, and system reliability. Clearly, it is not sufficient to simply present the same information in an electronic form.

In the short term, there is a potential concern about the willingness of technicians to embrace the use of computerized manuals. To explore this concern, the survey included questions about what manual format was preferred and why. The overwhelming majority of respondents (68%) indicated a preference for CD-ROM based or other electronic manual formats. Most technicians cite the speed of information search in their preference. The second most common preference (18%) was paper, with most respondents citing its portability as being advantageous. The willingness of technicians to learn to use computer manuals does not appear to be a concern and was not mentioned by any of the respondents.

3.4.2 Suggestions for Improvement.

Finally, technicians were asked to make recommendations for improving maintenance documentation. In some cases, responses reflected local problems within their own organization. These responses included complaints of limited access to computers or poor quality viewing and printing equipment that made the reproduced manual figures or text difficult to read. As such, these complaints are a reflection of the degree of investment in technology to support maintenance activities rather than of manual usability.

The most common suggestion was to expand the use of electronic manuals and the features they contain. Respondents commented that they would like to see more extensive use of electronic documents and a better utilization of the capabilities of computers through video and audio information, improved search capabilities, and more extensive linking of diagrams, illustrations, and parts catalogs.

- "Make all reference material available on CD-ROM with search software implemented in all programs"
- "Ability to cross-reference parts with procedures"
- "Digitize all schematics and wiring diagrams"
- "All should be on CD-ROM with better graphics ability"

The second most cited suggestion supports the fact that technicians do not have a problem with the accuracy of the documents, but take issue with the way procedures are written.

- "Make work steps easier to understand and make steps in a more logical order to accomplish work more efficiently"
- "Involve mechanics with the initial engineer/designer so the wording is more understandable"
- "Have experienced mechanics work with tech writers to be more articulate when describing work steps"
- "To really appreciate the problem, pick something and go to a manual and see the length of time it takes to figure out what to do"
- "Tech pubs should refer to maintenance departments and establish a group to improve these items together"
- "Put the guy in some coveralls and have them work on the A/C before sitting down and writing the tech pubs"

The following groups of comments refer to the general level of detail used in diagrams and illustrations.

- "Quit putting a small picture on a page and a lot of numbers referring to parts, you need a magnifying glass to see where the arrows are directed"
- "Show more detail on a components and systems"
- "Outline the steps more clearly, and if an item appears in the IPC, it should be mandatory to reference it in the manual"

Finally, the remaining comments refer to the speed at which manuals are updated or the speed of the revision process after problems are identified.

- "Quicker corrections to the manuals when I point out the errors"
- "Update illustrations and diagrams, replace old tech data"
- "Listen when someone reports an error"
- "Even when a problem is reported it doesn't seem to ever be corrected"

3.4.3 Important Note.

If the results of this survey were limited to an assessment of the quality of technical manuals, the current system of documentation would appear, from the perspective of the users, to be successful. With only a few exceptions, technicians consider manuals informative, consistent, and accurate. The manufacturers put considerable effort into verifying the accuracy of facts and formatting of technical documents, and the technician's rate them high in those areas. If the assessment stopped there, the results would indicate no need for improvement. However, when asked about the ease of use, efficiency, and suitability of the procedural information contained in the maintenance manual, a different pattern begins to emerge. The user's complaints, as reviewed above, identify usability as a significant issue. This likely reflects the extent to which manufacturers fail to take into account the way technicians use maintenance documents and perform aircraft maintenance.

3.5 INTERVIEW RESULTS.

Many of the issues voiced during the site visits and interviews centered on the difficulties technicians have locating needed information in the maintenance manual. When asked for a subjective estimate of the total job time spent searching for information, most technicians reported that, depending upon the job, as much as 50% of their time might be spent searching for information. The most common problems reported were determining effectivity and locating relevant procedures within the ATA chapter framework.

3.5.1 Effectivity.

The aircraft manufacturer and associated parts suppliers are constantly working to improve their respective products. Engineering or design improvements are incorporated into the production of the aircraft as they become available. Consequently, two aircraft of the same model and type can differ with regard to specific parts and components. This propensity for change continues once the aircraft is put into service, i.e., vendors or suppliers may go out of business, engineering changes and service bulletins may lead to safety or regulatory-related changes, and modifications may be made to upgrade avionics or optional equipment. The maintenance documentation must contain information specifying the parts and components unique to each aircraft.

As mentioned in Phase 1, manual writers must provide references for all of the engineering changes, service bulletins, optional equipment, and superceded parts. When a technician begins a maintenance task, they must first establish the effectivity of all options that apply to the aircraft they are working on, as well as the status of any modifications or service bulletins. Usually, technicians must search through all of the possible options referencing the aircraft tail number against the parts list. Technicians repeatedly mentioned difficulty in determining effectivity of parts and systems. As noted above, technicians can spend as much as 50% of the total task time determining effectivity.

3.5.2 Navigating the ATA Framework.

The original ATA specification 100, and the new *i*spec 2200 that replaces it, were developed to provide standards for the format and layout of technical manuals. In addition to page formatting and text layout guidelines, the ATA specification details an outline for the organization of material within the manual. As part of the ATA standard, manufacturers agree to conform to a common industry standard for chapter organization. For example, landing gear information will always be located in chapter 32, and flight controls will always be detailed in chapter 27. Standardization minimizes the time technicians need to learn to use new manuals and makes it easier for them to switch from one manual to another. This standardization improves manual usability and user experience with manuals.

However, even when using the framework of the ATA specification, there are occasions when the manual writer must make decisions regarding the best location for component description or procedure details. For example, maintenance information pertaining to the wings is located in chapter 57 and fuel systems are located in chapter 28. Because fuel tanks are located in the wings, interfacing parts belonging to the wing may appear in diagrams of the fuel system but only be referenced in the manual chapter dealing with the wing. In this case, the technician must determine which system each component belongs to and where the relevant information can be found. These organization decisions are common to all parts of the aircraft and must be made throughout the manual. Because there is some leeway in the organization of information within the chapter structure, writers may make decisions based on engineering classification of systems or ease of writing. While the design and manufacturing processes may suggest natural answers to these questions, the response of the technicians indicates that the organization choices made by writers often creates confusion and difficulty for technicians when attempting to find information.

3.5.3 Design of Procedures.

The third issue raised during site interviews was the ordering and breakdown of procedural steps. Rather than listing the same procedural steps every time a similar task must be accomplished, most manuals will list them once, and call them out when applicable. This subtask call-out arrangement reduces overall manual size, ensures the consistency of information, and increases efficiency of document revisions. If a procedure must be revised, it is easier to change one instance rather than multiple instances of that information. In a paper-based manual, the subtasks referenced in a maintenance procedure may be distributed throughout the manual, forcing the technician to jump from one section to another. In some cases, a procedure will call for only selected steps of a given subtask, further fragmenting the flow of procedural steps. This subtask distribution is well suited to a linked, electronic document that allows the user to follow links to each subtask and then return to the original procedure. In paper or microfilm formats, the technician must manually search for and retrieve the subtask information. The time spent searching for relevant subtasks and the disruption of workflow increases the likelihood that a technician may miss steps or lose their place within the procedure.

4. DISCUSSION.

Before discussing the major findings of this study, it is important to first review the purpose of the investigation. The primary object of Phase 2 was to assess the degree of error present in fielded manuals and to assess their usability from the perspective of the user. The following discussion is organized into four main sections reviewing the validity of survey responses, findings pertaining to errors in the manuals, quality of manuals, usability ratings, and the potential impact of each of these factors on safety.

4.1 RESPONSE VALIDITY.

In order to determine the degree to which the survey respondents were representative of the larger population of aircraft technicians, a series of questions regarding maintenance safety behaviors were included. These questions were adapted from a previous survey conducted for the Australian Transportation Safety Bureau (ATSB), by Hobbs and Williamson [7], of safety behaviors of maintenance technicians. Survey data is subject to a variety of potential biases. Participants may bias their responses to satisfy what they believe the research objective to be, in fear of how it may affect their employment, or how it might reflect on them or their profession. Although it is not possible to eliminate all sources of response bias, one can gauge the unique bias of a group by comparing responses with results of similar studies. Differences in the response of two groups to similar questions may suggest the presence of unique response biases. A comparison of the results of the present study, with those of Hobbs and Williamson, indicates no marked differences in response patterns between the two populations of technicians. For example, in Hobbs and Williamson's survey, 34% percent of technicians reported occasionally, often, or very often failing to refer to the parts catalogue when selecting parts. In response to the same question, 33% of technicians who participated in this survey made the same responses. Likewise, 91% percent of respondents in Hobbs and Williamson's survey report never or rarely failing to refer to the maintenance manual on an unfamiliar job. Eight-six percent of respondents in this survey responded in a similar fashion. The similarity of responses is notable, considering the differences in nationality and regulatory controls to which each is subjected. More importantly, the results suggest that the replies and experiences of our pool of respondents is representative of aircraft maintenance personnel in general.

4.2 SUMMARY OF MAIN FINDINGS.

Because of concerns about the potential impact on safety, manual error has received greater attention recently. This is partly in response to a number of aircraft accidents attributed, at least in part, to maintenance errors. In the absence of hard data, the magnitude of this problem could not be estimated. This project represents an attempt to determine the extent and potential impact of errors in aviation maintenance manuals.

In general, the results indicate that the number of errors in fielded manuals may be relatively low given that most respondents reported rarely or never finding errors in text (54%), illustrations (63%) or diagrams (66%). One might be alarmed to see that roughly 35% to 45% of respondents reported occasionally or often finding errors in these areas. However, many of these errors, such as misspellings or format errors, would have little impact on maintenance or aircraft safety.

Comparisons of errors found in text versus diagrams shows that errors appear to be more frequent in text. This does not mean that textual information is necessarily less accurate than the information presented in diagrams or illustrations. This pattern more likely reflects the fact that text procedures represent a proportionally larger part of the manual, or it may be the result of the difficulty of putting complex procedures and descriptions into words versus presenting that information in graphical form.

Interestingly, comparisons of large and smaller FAR Part 25 aircraft indicate that the only significant differences were related to the perceived frequency of text errors, with error being reported more frequent in smaller FAR Part 25 aircraft. It might be expected that developing manuals for large transport aircraft would in some way be different from other FAR Part 25 aircraft because of the level of customization and system complexity. While there are differences in the user's perception of error between the manufacturers of these aircraft, the degree of similarity in responses is surprising, in light of the lack of common error controls being employed.

User feedback is one of the primary factors influencing the development of technical documentation. Each company employs its own set of procedures to develop a manual they think users will accept. In addition to user satisfaction, these procedures must strike a balance between a number of competing demands including manual development costs, time constraints, regulatory requirements, and safety. Each manufacturer has attempted to achieve a balance among these competing demands, and the variety of approaches adopted reflects the uniqueness of those solutions. Considering that the majority of users (56%) rate the quality of manuals as being good to very good, it would appear that the demands of users are being met.

4.3 QUALITY OF MANUALS.

If the manufacturers perception of the quality of their manuals is based on the feedback obtained from users, this perception may be in error because they do not know the number of errors that go unreported. More importantly, it places a greater emphasis on factual and typographic error (e.g., incorrect part numbers and misspellings) while providing little information about the usability of the document and procedures. It is quite possible for a document to be factually correct and free of spelling, grammar, and formatting errors, yet fall short of the goal of good usability. For example, Patankar and Kanki [8] outline changes in the engine change procedure of a Boeing 737 that resulted in a significant decrease in total job hours. The factual information remained the same, but improvements in the usability of the document resulted in a more efficient, and presumably safer procedure.

The number of disagree and strongly disagree responses to the following questions reflect a problem with manual usability: "the manual describes the best way to do a procedure" and "the manual writer understands the way I do maintenance." What is of issue here is whether the procedural steps can be easily followed, whether procedures progress in a logical and efficient manner, and whether the task instructions take into account possible extenuating circumstances or the difficulty of certain tasks. When writing a task procedure, the writer must decide what order to follow, the number and extent of warnings to include, how much background information to include, and how much detail to provide. In many cases, these choices are made based on either design standards or personal experience. Ideally, these decisions should be guided by observation of individuals performing the task and/or feedback from technicians. The farther removed the writer is from the task demands, the less aware they will be of potential usability problems.

Clearly, there is a need to provide maintenance technicians with documentation that not only conveys the technical information necessary to maintain an aircraft, but also presents it in such a way that best matches the way technicians do their job. All manufacturers have systems in place to gather feedback from operators about the accuracy of manuals, but gathering data about user perceptions of manual usability has not traditionally received as much attention. This type of feedback requires more detailed communication from the operator and a greater commitment from manufacturers to gather that feedback. The majority of current response forms and suggestion-reporting methods are tailored more toward the traditional idea that errors are being limited to incorrect information. When evaluation of manual quality is extended beyond information error into issues of document usability, a reactive approach becomes less effective because user's are unlikely to report usability problems and even less likely to make nontechnicians able to understand those problems. Users may not take time to provide feedback, may fail to articulate the problem adequately, or the writer may fail to appreciate the cause or extent of the user's difficulty. Analysis of survey responses to the question "How often do you report errors when you find them?" reveals that in many cases technicians simply do not take the time to report errors. Because users represent the last line of defense in ensuring manual quality and accuracy, any failure to report an identified error can be considered a degradation of the entire system. The goal then becomes one of determining why users might fail to report errors and how the reporting system might be improved. In both the on-site interviews and survey comments, technicians frequently commented that they received little feedback or saw no changes to the manual as a result of their suggestions. If there is a perception that no one is listening to their input, the technicians will simply stop providing feedback. What remains unclear is where this breakdown is occurring. Supervisors may fail to pass information on to the writers and engineers within their operator, those writers and engineers may fail to pass it on to the manufacturer's service representative, or the manufacturer may fail to adequately respond to the input of the service representative. In many cases, a change request may be denied but the reporting technician is left unaware of the reasons for this decision. If technicians believe that their comments were ignored, they will be less likely to report problems in the future. In order for the reporting process to work, a greater commitment is required from both the operator and the manufacturer to ensure that identified problems are reported in sufficient detail, and a follow-up response is provided to the reporting technician even when no changes are made.

Potential consequences of usability problems in technical documents include the safety, speed, and cost of aircraft maintenance. In a complex, time-limited environment like aircraft maintenance, these factors are interdependent. Every time a technician has difficulty finding information in the manual, the speed of maintenance is slowed and revenue is lost. Because of the financial impact and schedule demands, the pressure to complete work quickly can push individuals to take shortcuts. If the technician has difficulty understanding the wording of a manual procedure, they may be motivated to devise an alternate method of completing that task or ask another technician for help. With the average level of experience represented in this survey (13 years), this may not result in a problem. However, whenever users are pushed to work around usability problems, the potential for safety violations increases.

Some aspects of manual usability, such as formatting, consistency, and reading level, can be controlled through standardization and guidelines. The need for clarity and consistency across manuals has been the motivation for the ATA guidelines regarding the layout and organization of maintenance documentation. The ATA Spec 100/*i*spec 2200 has been an effective means of establishing a baseline for manual quality and structure. The pattern of responses to survey questions pertaining to manual quality, consistency, and ease of use suggest that the standards adopted by the ATA have been effective. The use of consistent style and formatting is one important aspect of document usability. However, within the framework of the ATA specification, the writer must make decisions about details such as the ordering of procedural steps, the wording of procedures, the use of illustrations, and level of detail. Questions about wording and sentence structure can be addressed with the use of restricted vocabularies or style guides, but the unique nature of each maintenance procedure limits the usefulness of any checklist or standard method for describing a procedure. Writers and engineers must rely on their writing experience and knowledge of the aircraft systems when deciding how best to describe a procedure. Likewise, a technician will rely on their maintenance experience and knowledge of aircraft systems when interpreting and applying maintenance information. Unfortunately, the experience and knowledge of the writer and engineer may be quite different from the experience and knowledge of the technician. This potential mismatch can result in other usability problems in technical documentation. At least one participating manufacturer has started to address some of these issues by validating maintenance manual procedures. Unfortunately, the responses included in the current survey do not include enough references to validated manuals to ascertain the effects on user perception.

In order to understand how usability problems occur, it is necessary to understand the cognitive processes involved in reading and applying information. Hayes and Flower [9] provide the following outline (see figure 10) adapted from Thibadeau and Just [10] of the cognitive process of reading to comprehend information. The process of reading can be thought of as a flow from the basic level of letter and word identification to the most advanced level of understanding the intent of the presented message and applying the information it contains. Progression along this continuum from decoding of words to inference of intent is a move from text-centered, to information- and reader-centered processes [11]. Any written passage can be evaluated for how well it performs at any level along this continuum, but the criteria for evaluation changes in the progression from text- to reader-centered stages.

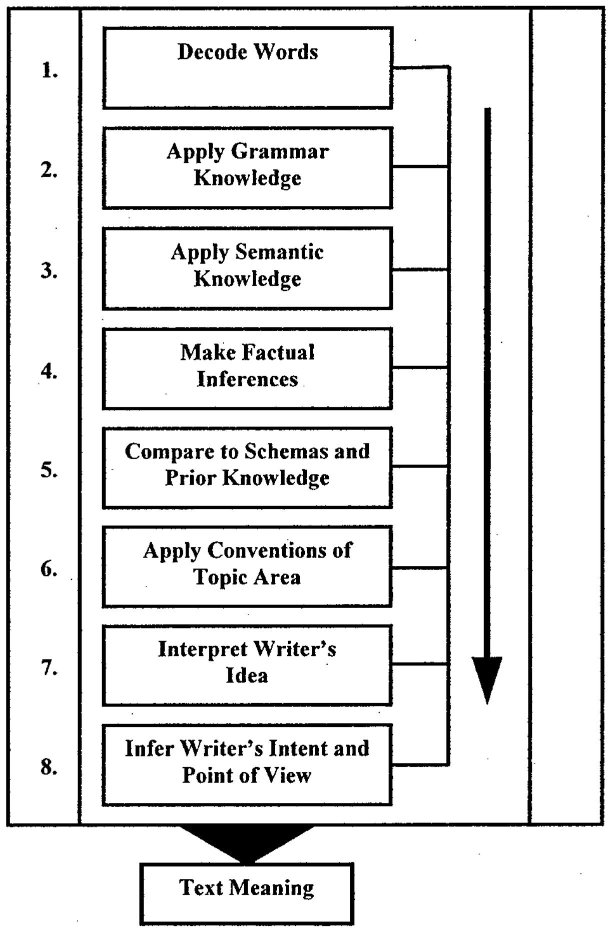


FIGURE 10. THE PROCESS OF READING TO COMPREHEND
(Adapted from references 9 and 10)

In the early stages of the cognitive model, the reader identifies words, applies rules of grammar, and combines sentences to create a semantic interpretation of the text. This is a rule-driven process, based on the reader's knowledge of the language. Errors identified during these stages include misspelling, incorrect use of punctuation, and inappropriate usage of words. These mechanistic problems can be eliminated through spelling and grammar checking and using style guides or restricted vocabularies. The impact of errors at these stages on the readers comprehension will vary with the severity of the error and the expertise of the reader. Certainly, a typographic error might result in a safety problem if that error were to occur in a part number, a tolerance level, a pressure level, or torque value. However, it is more likely that typographic and grammatical errors will be seen as annoyances rather than safety problems.

Stages 1 through 3 of the model focus on the mechanical structure of the text, while stages 4, 5, and 6 shift the focus beyond the text itself to the topic area the text is referencing. The majority of procedures currently in place are meant to limit problems related to the early stages of reading cognition. In order to address problems related to the topic area, requires an appreciation of the cultural and institutional environment associated with aircraft maintenance. It is at this stage that many of the problems related to language translation occur. Even differences within the same language can cause problems when addressing topic area conventions. For example, the British and American use of the terms "torch" and "flashlight." A British writer's description of a fuel tank inspection procedure could potentially lead to disaster for an American technician if they fail to understand the usage of the word torch.

Finally, stages 7 and 8 involve the combination of semantic knowledge, conventions of the topic area, and the reader's expectations to arrive at an interpretation of the writer's intent. If the writer fails to account for the presuppositions of the reader, all other aspects of the text can be accurate, yet still be misdirected. At best, the reader may simply discount the importance of the writer's point of view. At worst, the reader may misunderstand the point of view of the writer and perform a procedure in a manner contrary to what the writer intended. Minimizing the possibility of failure at any point along the continuum requires a combination of error-checking and proofreading procedures, along with clear communication between writers and readers throughout the writing process and beyond.

4.4 FUTURE USABILITY ISSUES.

The responses included in this survey apply primarily to paper-based manual formats. There is a slow but steady trend to replace these manuals with computer-based maintenance information. The move from paper-based to electronic manuals will address many of the usability problems reported by technicians. Electronic manuals can be updated and distributed quickly, take up less space, and can make searching for information much easier. In addition, they may include text, audio, and video presentations to provide a more detailed description of procedures. Even with the potential benefits of moving to electronic manuals, the change of format introduces new usability issues. These include the design of the interface, search functions, size and readability of video displays, document navigation, and equipment reliability. Every subsequent development in the delivery of technical information will also require careful scrutiny of usability concerns.

5. IMPLICATIONS.

The results of the survey suggest that the users of aviation technical manuals generally perceive the manuals favorably. They did not report significant problems with the accuracy or general quality of the documents. The main criticism shared by most users pertains to usability. More specifically, users comment that, in many cases, the document procedures are inefficient and/or fail to consider the demands of the maintenance environment. Considering that these concerns were shared by technicians using manuals from a diverse set of manufacturers, it is expected that improving the usability of technical documents may have a broad range of benefits ranging from improved user satisfaction to improved safety and savings in maintenance costs. The goal of Phase 3 of this effort will be to outline recommendations and procedures to improve document usability.

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APPENDIX A—SAMPLE SURVEY QUESTIONNAIRE

FAA Mechanic Questionnaire

Please list the aircraft you currently work on and indicate the length of time you have worked on them:

Aircraft Name	Specialty Area (e.g. wiring, avionics, engines, ALL)	Less than 3 months	3 – 6 months	6 – 12 months	1 – 3 years	More than 3 years

Please list the TWO aircraft you have worked on the MOST (Aircraft A and B). Then, answer the following questions based on those aircraft.

Aircraft A: ____________________ **Aircraft B:** ____________________

In a typical week, how often do you use the following manuals?	Aircraft A < 5 hrs	Aircraft A 6-10 hrs	Aircraft A 10-30 hrs	Aircraft A > 30 hrs	Aircraft B < 5 hrs	Aircraft B 6-10 hrs	Aircraft B 10-30 hrs	Aircraft B > 30 hrs
Aircraft Maintenance Manual (AMM)	1	2	3	4	1	2	3	4
Component Maintenance Manual (CMM)	1	2	3	4	1	2	3	4
Engine Cleaning, Inspection, and Repair Manual (CIR)	1	2	3	4	1	2	3	4
Engine Shop Manual (EM)	1	2	3	4	1	2	3	4
Fault Isolation Manual (FIM)	1	2	3	4	1	2	3	4
Service Bulletin (SB)	1	2	3	4	1	2	3	4
Structural Repair Manual (SRM)	1	2	3	4	1	2	3	4
Aircraft Illustrated Parts Catalog (IPC)	1	2	3	4	1	2	3	4
Wiring Manual (WM)	1	2	3	4	1	2	3	4
Task Cards	1	2	3	4	1	2	3	4
Company (or in-house) developed maintenance aids	1	2	3	4	1	2	3	4
Other ____________________	1	2	3	4	1	2	3	4

How often have you found an error in:	Aircraft A Never	Aircraft A Very Rarely	Aircraft A Occasionally	Aircraft A Often	Aircraft A Very Often	Aircraft B Never	Aircraft B Very Rarely	Aircraft B Occasionally	Aircraft B Often	Aircraft B Very Often
Text Descriptions or Procedures	1	2	3	4	5	1	2	3	4	5
Illustrations	1	2	3	4	5	1	2	3	4	5
Diagrams	1	2	3	4	5	1	2	3	4	5

How would you rate the following aspects of the Aircraft Maintenance Manuals?	Aircraft A Very Poor	Aircraft A Poor	Aircraft A Neutral	Aircraft A Good	Aircraft A Very Good	Aircraft B Very Poor	Aircraft B Poor	Aircraft B Neutral	Aircraft B Good	Aircraft B Very Good
Usefulness of information	1	2	3	4	5	1	2	3	4	5
Quality of the illustrations	1	2	3	4	5	1	2	3	4	5
Quality of diagrams	1	2	3	4	5	1	2	3	4	5
Clarity of text descriptions	1	2	3	4	5	1	2	3	4	5

General Satisfaction	Aircraft A Strongly Disagree	Aircraft A Disagree	Aircraft A Neutral	Aircraft A Agree	Aircraft A Strongly Agree	Aircraft B Strongly Disagree	Aircraft B Disagree	Aircraft B Neutral	Aircraft B Agree	Aircraft B Strongly Agree
I find the manual information to be very informative.	1	2	3	4	5	1	2	3	4	5
There is never enough information in the manual when I need it.	1	2	3	4	5	1	2	3	4	5
Using these manuals is frustrating.	1	2	3	4	5	1	2	3	4	5
Sometimes I feel like I need a manual to understand the manual.	1	2	3	4	5	1	2	3	4	5
The information in the manual is inconsistent.	1	2	3	4	5	1	2	3	4	5
The maintenance manual describes the easiest way to conduct each procedure	1	2	3	4	5	1	2	3	4	5
The writers of the manual understand the way I do maintenance procedures.	1	2	3	4	5	1	2	3	4	5
The manuals help me to be more productive.	1	2	3	4	5	1	2	3	4	5
The manuals are easy to use.	1	2	3	4	5	1	2	3	4	5
The manuals were easy to learn how to use.	1	2	3	4	5	1	2	3	4	5
I am satisfied with the manuals.	1	2	3	4	5	1	2	3	4	5
I easily remember how to use the manuals.	1	2	3	4	5	1	2	3	4	5
An inexperienced mechanic could repair the aircraft using just the manual	1	2	3	4	5	1	2	3	4	5

	Aircraft A	Aircraft B
Did you receive training on how to use the manuals?	YES NO	YES NO
Did you find the training to be adequate?	YES NO	YES NO
Do you receive training on the manuals as updates are made?	YES NO	YES NO

At work in the last year or so, how often have you:	Never	Very Rarely	Occasionally	Often	Very often
Been misled by confusing documentation	1	2	3	4	5
Not referred to the maintenance manual or other approved documentation on a familiar job	1	2	3	4	5
Not referred to the maintenance manual or other approved documentation on a unfamiliar job	1	2	3	4	5
Not referred to the parts catalogue when selecting a part	1	2	3	4	5
Done a job a better way than that in the manual	1	2	3	4	5
Adjusted or rigged a system incorrectly because the documentation was unclear or misleading	1	2	3	4	5
Assembled a component or system incorrectly because the documentation was unclear or misleading	1	2	3	4	5

If you have discovered a poorly worded or unclear procedure, how often did it result in :	Never	Very Rarely	Occasionally	Often	Very Often	
A part being damaged	1	2	3	4	5	N/A
The need for help from another mechanic	1	2	3	4	5	N/A
A mechanic finding their own way to do a procedure	1	2	3	4	5	N/A
An aircraft being released in an unairworthy condition	1	2	3	4	5	N/A
A mechanic being blamed for a mishap	1	2	3	4	5	N/A

	Never	Very Rarely	Occasionally	Often	Very Often	
In general, when a problem is discovered in a manual, how often is it reported?	1	2	3	4	5	N/A

What manual format do you use most often?

_____ Paper
_____ Microfilm
_____ Microfiche
_____ CD-ROM
_____ Portable Maintenance Aid
_____ Other (specify) ____________________

Which manual format do you prefer? ______________ **Why?** ____

____

What suggestions do you have for improving maintenance manuals? ________________________________

____

____

——————————BIOGRAPHICAL INFORMATION——————————

Company/Location: ________________________ Job title: ______________________

Education level:
_____ High school graduate
_____ Some college
_____ Bachelor's degree
_____ Graduate degree
_____ Other (specify) ______________

FAA Certification:
____ None
____ Yes (specify) ____________________

Typical work hours:
Start time: __________ AM PM
End time: __________ AM PM
Total hours per week: ______

Maintenance Training (check all that apply):
_____ Technical School ________ years
_____ Military _______ years
_____ Other _______ years

Gender: M F
Year of birth: __________
Years in current position: ________
Years with the company: ________

Type of Maintenance Typically Performed:
_____ Line Maintenance
_____ Base Maintenance

APPENDIX B—STATISTICAL ANALYSIS OF LARGE VERSUS SMALLER AIRCRAFT

	t-test for Equality of Means			
	t	Degrees of Freedom	Significance (2-tailed)	Mean Difference
Found Error in Text	-2.461	295	0.014	-0.257
Found Error in Illustrations	-0.891	293	0.374	-0.083
Found Error in Diagrams	-1.399	292	0.163	-0.130
Usefulness of Manuals	1.182	285	0.238	0.107
Quality of Manuals	-0.347	295	0.729	-0.036
Quality of Diagrams	-0.435	294	0.664	-0.044
Clarity of Text Descriptions	2.317	296	0.021	0.254
Manuals are Informative	2.012	295	0.045	0.185
There is Never Enough Information	-3.363	295	0.001	-0.351
Using the Manual is Frustrating	-0.586	295	0.559	-0.068
I Need a Manual to Understand the Manual	-0.422	293	0.673	-0.049
The Manual Information is Inconsistent	-2.749	296	0.006	-0.273
The Manual Describes the Easiest Way to Do a Procedure	0.273	294	0.785	0.028
The Manual Writer Understands How I do Maintenance	0.071	296	0.943	0.007
Manuals Help Me To Be More Productive	0.669	296	0.504	0.070
Manuals are Easy to Use	0.623	290	0.534	0.062
Manuals are Easy to Learn	0.710	295	0.479	0.073
I am Satisfied with the Manual	1.110	291	0.268	0.125
It's Easy to Remember how to use the Manual	-1.302	291	0.194	-0.122
Received Training on Manuals	1.039	299	0.299	0.057
Training was Adequate	1.938	275	0.054	0.113
Received Additional Training with Manual Updates	0.888	295	0.375	0.043
Been Misled by Manual Information	-0.576	145	0.565	-0.074
Not used a Manual on a Familiar Job	-0.883	146	0.379	-0.145
Not used a Manual on an Unfamiliar Job	1.104	146	0.271	0.137
Not Referred to IPC When Collecting Parts	4.439	146	0.000	0.653
Done a Job a Better Way Than in the Manual	-2.327	144	0.021	-0.358
Adjusted or Rigged Incorrectly due to Unclear Documentation	-1.154	144	0.250	-0.168
Assembled Parts Incorrectly due to Unclear Documentation	-0.186	145	0.853	-0.023
Education Level	-1.952	145	0.053	-0.447